A STATISTICAL METHOD FOR FORECASTING THE MOVEMENT OF NORTH AMERICAN ANTICYCLONES

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ABSTRACT

A statistical prediction method to forecast the movement of North American anticyclones is developed utilizing multiple linear regression analysis performed by the CDC 1604 electronic computer. The three predictands sought are the 24-hour change in central pressure and the eastward and northward displacements. Three multiple linear regression equations are derived.

The input data consist of observations of 150 anticyclones. A moving coordinate system is employed: the observed and derived predictor information is measured relative to the system center rather than a fixed geographical position.

Readily measured meteorological parameters are selected for the input data. These include point values of surface pressure, surface temperature, 500-mb height and average temperature of the layer from the surface to the 500-mb level. The 24-hour change of these variables is also included.

The regression equations are applied to 50 independent test cases. These statistical forecasts incur a vector error of 254 nautical miles for position, and a mean absolute error of 3.5 mb for pressure change at the system center.

The report is modeled after a similar study of cyclones conducted by Fredrick P. Ostby and Keith W. Veigas [1960].

The authors are indebted to Professor Frank L. Martin for his advice and guidance during the progress of this study. Acknowledgment is also due Professor J. R. Borsting for his invaluable assistance in the statistical analysis of the investigation.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

mb	Millibar(s)
t_0	Observation time
t_0-24	24 hours prior to observation time
p	Surface pressure
Δp	24-hour surface pressure change
T	Surface temperature
ΔT	24-hour surface temperature change
L	Latitude
λ	Longitude
I	Anticyclone intensity
z	500-mb height
Δz	24-hour 500-mb height change
$\bar{T}$	Mean temperature of the layer from surface to 500 mb
F	Statistical value for ratio of mean squares
RMS	Root mean square
Y	Actual value of dependent variable
Y'	Predicted value of dependent variable
X_i	Independent variable i
a_i	Coefficient of independent variable i
N'	Predicted value of dependent variable for south-north displacement
E'	Predicted value of dependent variable for west-east displacement
P'	Predicted value of dependent variable for change in sea-level pressure at the system center
P.R.	Percent reduction of variance; also coefficient of determination, (R^2)

t	Statistical value for test of significance
s_y	Standard error
S_y	Standard error of the estimate
χ^2	Chi square statistical frequency distribution
k	Number of independent variables in a regression equation
n	Sample size
R	Multiple linear correlation coefficient
R^2	Coefficient of determination; also percent reduction of variance (P.R.)
nm	Nautical miles
m	Map factor
N	Observed south-north displacement
E	Observed west-east displacement
P	Observed change in sea-level pressure at the system center
Const	Constant (a_0)

1. Introduction.

Recent advances in statistical theory combined with the perfection of the modern electronic computer make statistical methods useful in nearly every area of scientific endeavor. Such machine analyses are readily adaptable to the collection, investigation and interpretation of quantitative data in a myriad of fields. Logical statistical analysis is especially useful to the meteorologist.

The meteorologist collects data which are relatively complex and which are the result of numerous factors. Thus, occurrences of meteorological phenomena are not independent. Statistical predictions are only average values based upon the particular period examined. We never do know the true probability of a meteorological phenomenon; we can only form an estimate of it based on past experience. Essentially accurate conclusions, of course, may be drawn from rough estimates, but in their use the element of danger is correspondingly greater. Sound judgment must be constantly invoked to guard against false conclusions being drawn.

The physicist and the biologist utilize laboratory techniques to deal with problems of multiple relationships. Under laboratory conditions all the variables except the one under consideration can be held constant while the latter's effect upon the dependent variable can then be determined. For the problems of the meteorologist, however, such laboratory controls cannot be imposed. Rainfall, cloud cover, temperature and pressure vary constantly and only their combined effect can be noted. Hence, the meteorologist must frequently apply methods of multivariate statistical analysis in order to handle serially-correlated data.

Statistics may be collected on most observations, but the use of statistical methods in these studies does not always lead to results of universal validity. At best the statistical may be only one of many approaches to the explanation of physical phenomena. Furthermore, statistical inferences must always be scrutinized with care. On the other hand, the successful application of statistics and statistical methods to meteorological problems may be sufficiently emphasized, at this point, by calling attention to only a few of the significant statistical studies in the field. Useful contributions have been made by Charney [1954], Miller [1958], Ostby and Veigas [1960], and Hull [1961].

The aim of this study is to utilize statistical methods to develop multiple linear regression equations for predicting the behavior of migratory anticyclones in North America. Such equations would be useful tools to both the synoptic and numerical weather forecaster.

2. Background.

The development of anticyclones, from the standpoint of the mass and temperature fields, is the reverse of that of cyclonic systems. High-level anticyclogenesis appears to be associated with the accumulation of mass in the lower stratosphere, accompanied by cooling. This cooling can be advective or due to ascent resulting from horizontal convergence in the upper troposphere. For a complete discussion of the theories dealing with the origin and structure of anticyclones, the reader is referred to an article by Wexler [1951].

Harrison [1947], investigating the steering of anticyclones, found that about 68% of the North American anticyclones were steered by the flow at 700 mb. Longley's [1947] results showed that about 75% were steered by this same current. However, if either of the above

techniques are to be applied to predict the movement of a surface anticyclone, first the 700-mb flow pattern must be correctly forecast. This of course reduces the value of the methods to the forecaster.

George and associates [1960] have devised a semi-objective technique for forecasting the movement of anticyclones for 24-hour and 48-hour periods. This solution uses the isotherm ribbon at 850 mb for determining the direction of movement, and the first definite wind maximum, "at 700 mb transverse to the current flow adjacent to the surface high center," to determine the speed of movement. An independent data check by George et al. showed the average error in position to be 265 miles for the 24-hour forecast. However, when utilizing this method, the flow pattern and its relation to the surface anticyclone remain somewhat subjective.

Successful objective forecast schemes are of considerable value in meteorology. In designing such a forecast procedure, one should, if possible, include as quantitative predictors those parameters considered important on a theoretical or semi-theoretical basis. However, loose reasoning may result if one attempts to assign cause and effect based upon statistical investigations. In this study no statement concerning cause and effect will be made. Rather, the results will be judged on the performance of the derived regression equations themselves.

3. Data sources.

The anticyclonic cases used in this study were taken from the Daily Series Synoptic Weather Maps analyzed by the National Weather Analysis Center for both the surface and 500-mb levels. These charts use a Polar Stereographic Projection true at latitude 60N. They were utilized for compiling both the dependent and independent test data. The sea-level

maps were analyzed for observations taken at 1230Z, while the 500-mb observations were taken at 1500Z.

Anticyclones for the dependent sample were selected from a geographic area extending from longitude 60 to 110W, between latitudes 30 and 60N. This area is outlined in figure 1. The period covered extended from October through March for the years 1953 through 1957 (1955 excluded). The final regression equations developed in this study should be applied only from October through March for those anticyclones which lie in the area defined above, henceforth called the forecast area.

In order for an anticyclone to be included in the sample, it had to be characterized by at least one closed isobar (5-mb interval). A further requirement was that the closed system had to remain within the forecast area during the succeeding 24 hours. If the system met both of the above requirements for an additional 24-hour period, it was included again in the sample as another case. In order to eliminate any possible bias, no single system was included a third time. These precautions are similar to those taken by Ostby and Veigas [1960] in their study of cyclones.

Based upon the above criteria, 150 cases were selected for the dependent sample data. The frequency distribution for this data by month and year is as shown in table 1. The number of cases examined varied from as many as 11 in February of 1953 to as few as one in February of 1957. The number of cases was a maximum during March (an average of 8.2) and a minimum in February (an average of 6.0).

The year 1955 was not included in the dependent sample in order that the data for this period might be retained for use in the independent test.

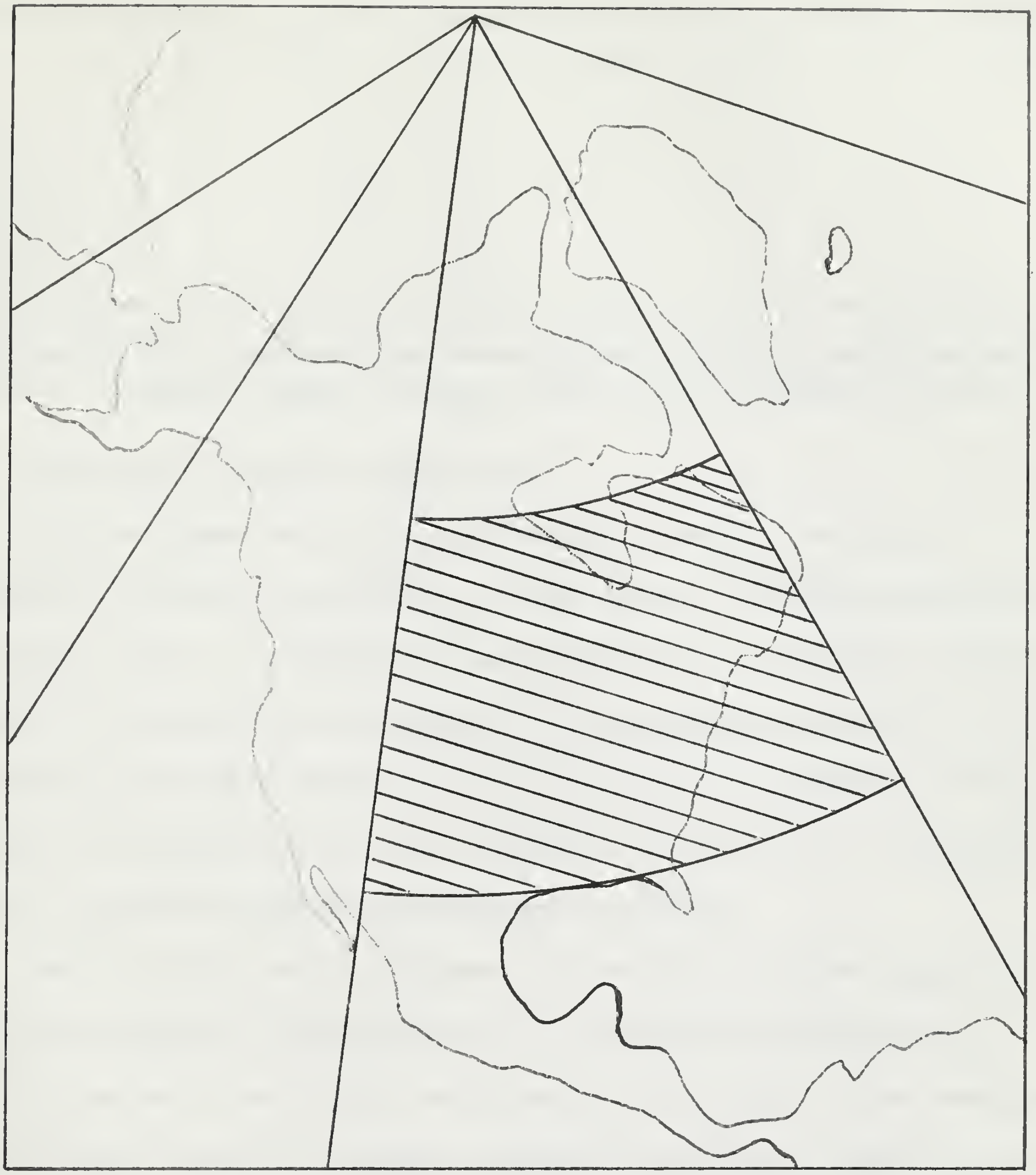

Figure 1. Forecast area.

	Oct	Nov	Dec	Jan	Feb	Mar	Total
1953	--	--	--	9	11	9	29
1953-54	--	9	7	8	5	10	39
1954-55	5	10	10	--	--	--	25
1955-56	--	--	--	6	7	9	22
1956-57	8	6	8	7	1	5	35
Total	13	25	25	30	24	33	150

Table 1. Dependent sample frequency distribution by months and years.

4. Selection of possible predictors.

The development of the modern electronic computer has made it possible to analyze statistically a large number of possible predictors with great speed. A screening program adapted to the CDC 1604 electronic computer is one method of carrying out the preliminary analysis of the reduction of variance necessary for the selection of predictors. This program is a modification of one originally written by M. A. Efroymson [1960] of the Esso Research and Engineering Company.

When utilizing such a technique, the selection of predictors must be purely objective. Consequently, it is imperative that the user specify precisely the initial set of possible predictors. The consideration of known synoptic or dynamic influences should be a factor in the selection process. Dynamic principles must be considered if any significant degree of success is to be expected.

A grid system capable of specifying point values of many atmospheric variables over the forecast area was devised. A moving coordinate system was selected similar to that of Ostby and Veigas [1960]. The observed and derived predictor information is measured relative to the anticyclone center rather than a fixed geographical position. The basic grid is shown in figure 2. It should be noted that this grid differs from that

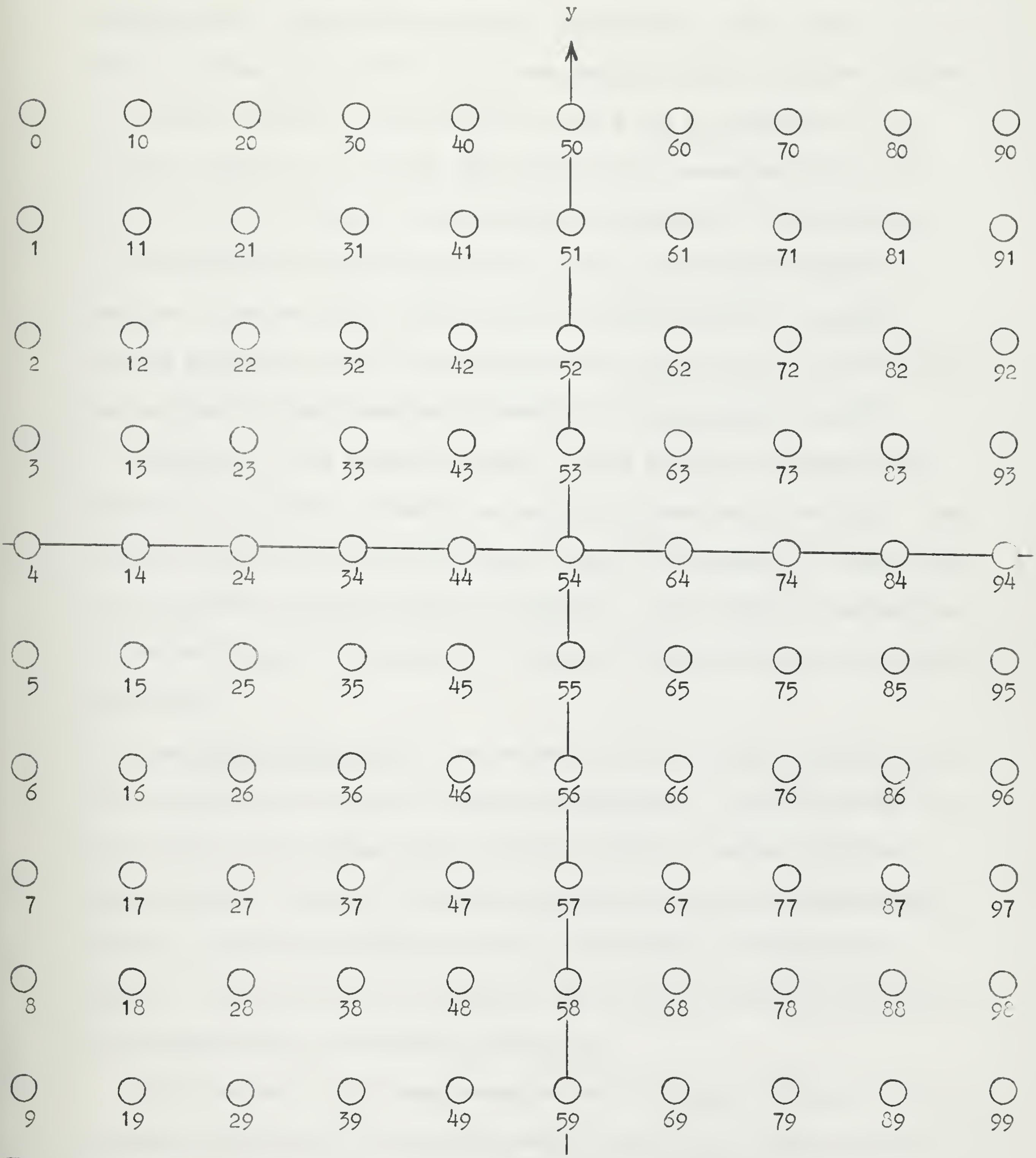

Figure 2. The basic grid. The y-axis is aligned along a meridian through the sea-level anticyclone.

of Ostby and Veigas in being square rather than determined by a latitude-longitude net. This square grid was constructed by first locating grid point 54 along latitude 45N. All remaining grid points are then located at 5-degree latitude intervals both in the x and y directions. This 5-degree interval is actually 300 nautical miles measured at 45N. The basic grid was utilized for determining all parameters. Grid point 54 is located over the system center with the y-axis aligned along the meridian. Smaller sets of grid points have been used for recording certain parameters, but these represent merely sub-sets of the basic grid and utilize the same numbering system for the various grid points.

Features of the present and past 24-hour pressure and temperature fields are embodied to furnish the majority of possible predictors. The sea-level chart and the 500-mb contour chart were employed to obtain the various possible pressure-height predictors. The procedures employed are listed below under the headings (a) sea-level predictors and (b) upper-air predictors.

(a) <u>Sea-level predictors</u>. Point values of the sea-level pressure field were recorded and included as possible predictors. The grid overlay was positioned on the surface chart with grid point 54 located over the system center. Values of sea-level pressure, read to the nearest whole millibar, were then recorded at the 54 grid points as indicated in figure 3. These values then specified the sea-level pressure field around the system center at observation time (t_0).

With the grid in the same relative position, point values of surface pressure 24 hours prior to the observation time (t_0-24) were recorded at the 13 shaded grid points, as also indicated in figure 3. These values were then used to specify 13 values of the 24-hour pressure-change field,

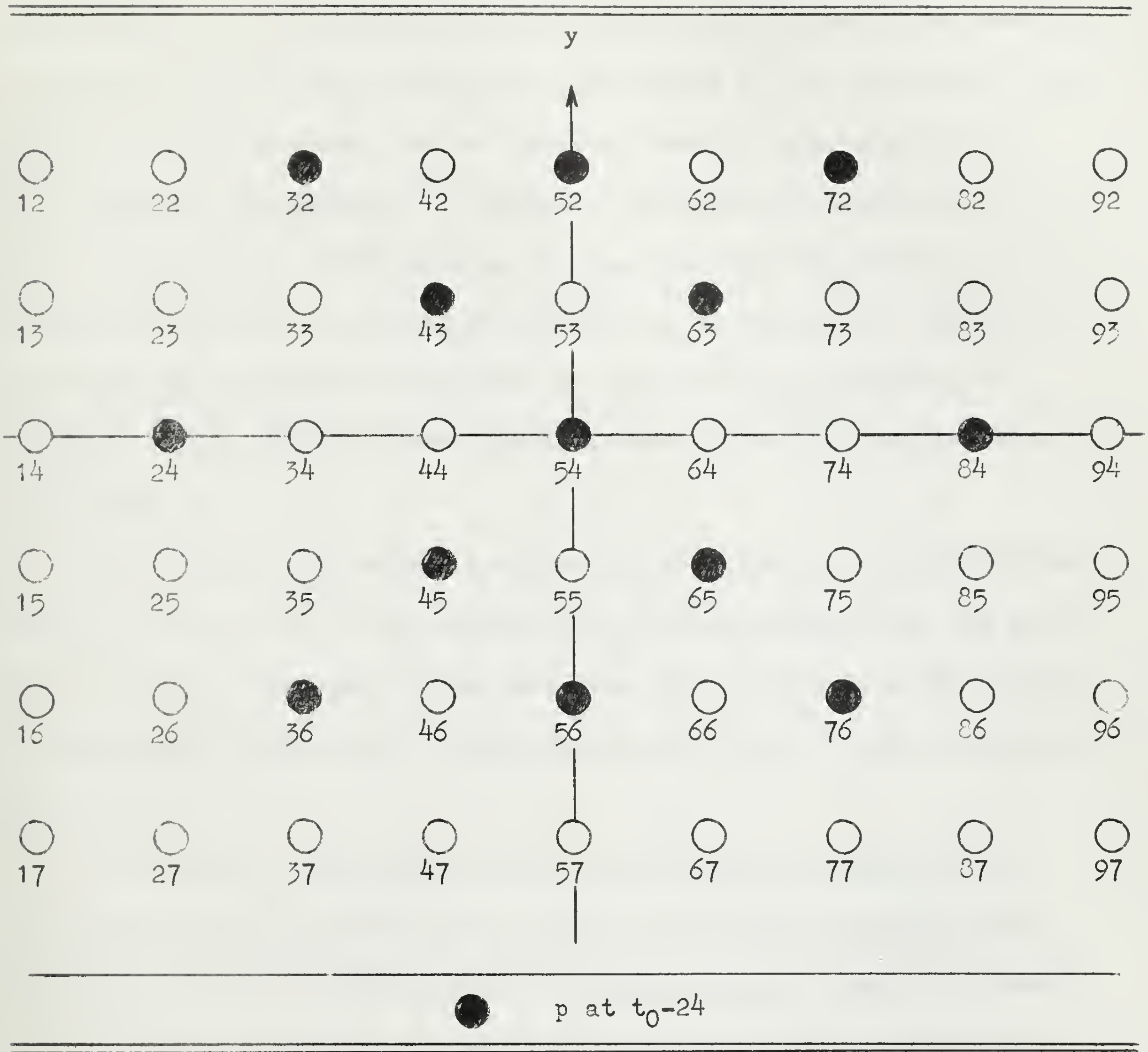

Figure 3. Grid points used to obtain sea-level pressures.

which were also included in the list of possible predictors.

The latitude, longitude and intensity of the anticyclone at t_0 were also recorded for use as possible predictors. The intensity was measured by averaging the surface pressure at grid points 43, 45, 63 and 65, then subtracting this average from the surface pressure at grid point 54.

(b) Upper air predictors. The values of the 500-mb predictors at t_0 were obtained from the 500-mb chart by positioning grid point 54 of the appropriate grid over the surface anticyclone center at t_0. Values of 500-mb heights were then recorded at 27 grid points as indicated in figure 4. These 27 values were also included in the list of possible predictors.

With the grid in the same relative position, point values of 500-mb height 24 hours prior to the observation time were recorded at the same 27 grid points. Recorded values were then used to determine the 24-hour 500-mb height-change field. These values were then included as possible predictors.

As previously stated, high-level anticyclogenesis appears to be associated with the accumulation of mass in the upper troposphere and lower stratosphere, together with associated cooling. Using the thermal pattern implied by a grid plot of temperature averaged in the vertical, one may use the dynamical concepts of Sutcliffe [1947] to deduce at least qualitative approximations to the upper-level convergence, and hence the evolution of the synoptic flow pattern of middle and upper layers of the troposphere. According to Sutcliffe, baroclinic development and movement of a sea-level anticyclone may be dynamically related to its position relative to the 1000-500 mb mean temperature field. In order to arrive at a representative mean-temperature field, the surface and 500-mb

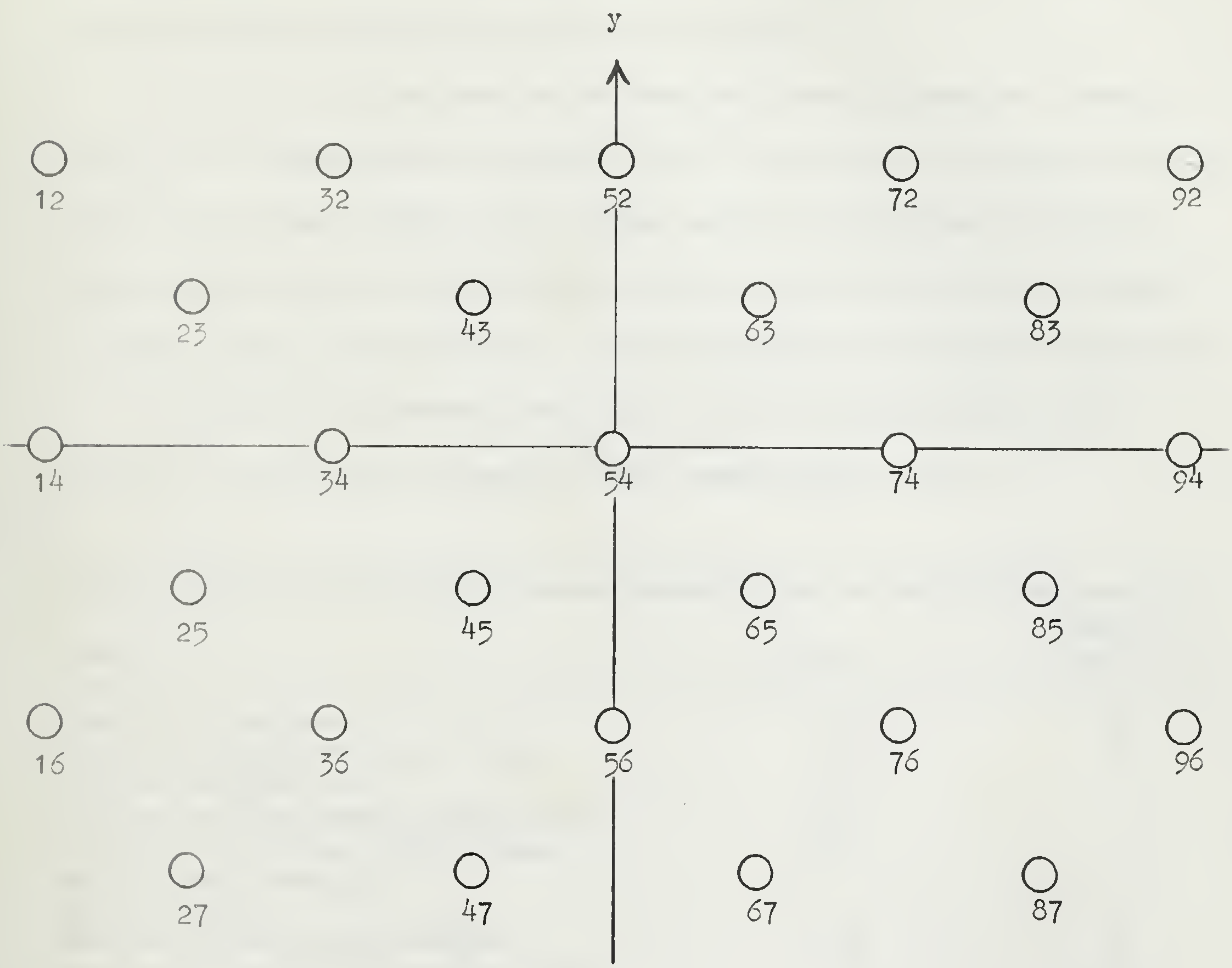

Figure 4. Grid points used to obtain 500-mb heights.

temperatures were recorded at 19 grid points, as indicated in figure 5. From these values the mean temperatures of the layer were calculated and also included in the list of possible predictors.

It should be noted that we are seeking linear regressions, whereas Sutcliffe's computations of advection of vorticity or of thermal vorticity involve non-linear fields. Any linear regressions obtained here which are consistent with his philosophy cannot be expected to give the degree of significance that would exist using appropriate non-linear regressions.

A total of 145 possible predictors plus three predictands were recorded. The possible predictors are summarized in table 2.

Predictor	Symbol	Number of predictors
Sea-level pressure	p	54
24-hour surface pressure change	Δp	13
Surface temperature	T	1
24-hour surface temperature change	ΔT	1
Location of surface anticyclone	L, λ	2
Anticyclone intensity	I	1
500-mb height	z	27
24-hour 500-mb height change	Δz	27
Mean temperature, surface to 500 mb	$\overline{T}$	19
		145

Table 2. Possible predictors included in the dependent data.

The data were checked and verified, then punched onto IBM cards. These cards were also checked and corrections inserted where discrepancies existed. The data were then transferred to magnetic tape, where they were stored in a form readily accessible for repeated machine analysis.

5. Reduction of data.

T.e reduction of the 145 possible predictors was accomplished by

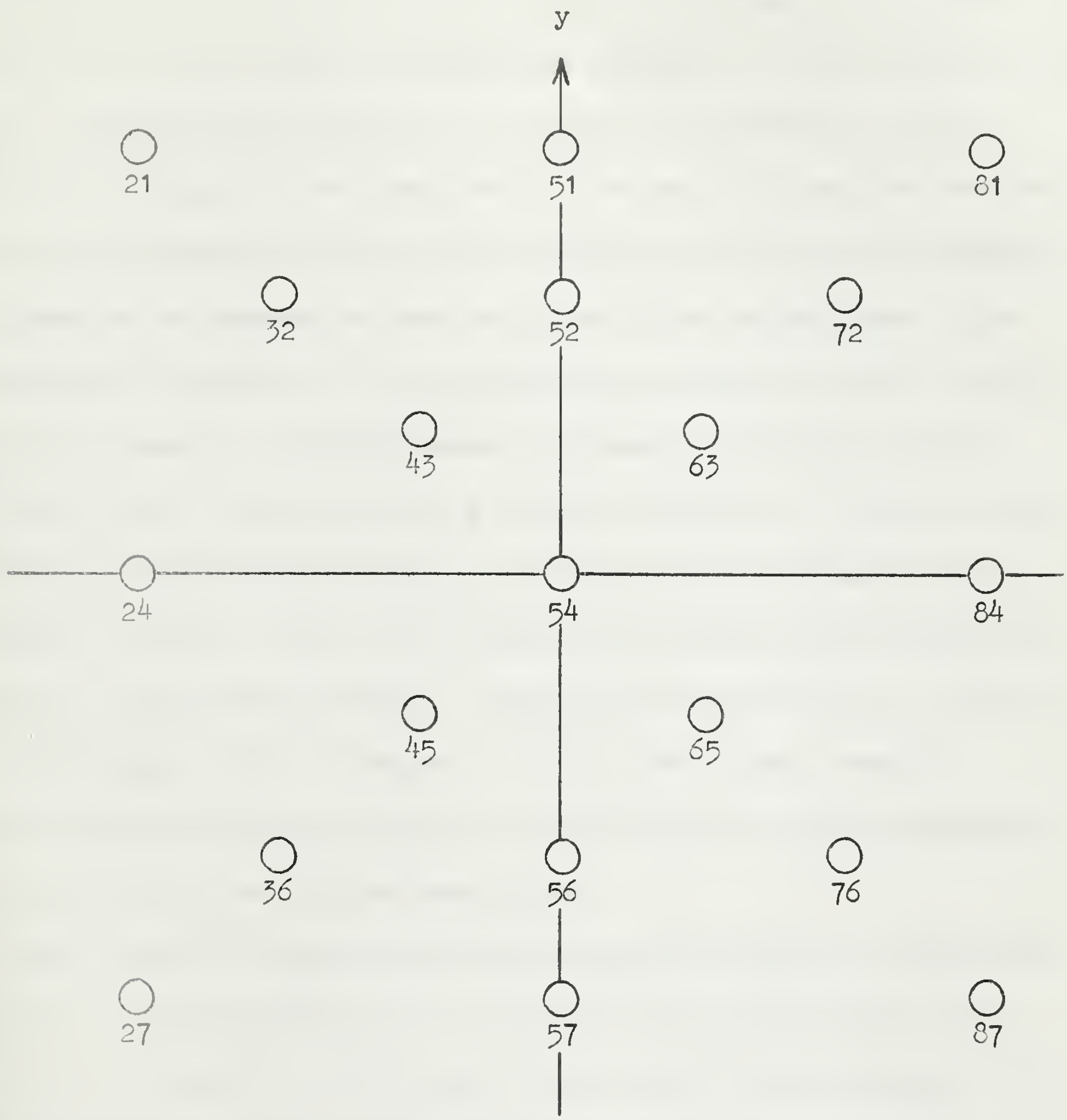

Figure 5. Grid points used to obtain sea-level and 500-mb temperatures.

employing a stepwise regression procedure. The regression equations were developed by adding one independent variable at a time at each step of the calculation. In each case, the variable added was that one which made the most significant improvement in "goodness of fit," based upon an F test. An important feature of the regression procedure is that a variable may appear to be significant in the early stages (and thus enter the linear statement of the problem), but after several other variables are added to the regression equation prove to be insignificant. The insignificant variable is then removed from the equation before another variable is added. This may happen, for example, when the variable initially added is approximately a linear combination of several other independent variables which have subsequently been introduced into the regression equation. Thus, only significant variables are retained for inclusion in the final equation. Additional variables are then added in the same manner. This procedure is repeated until each remaining variable examined fails to explain a specified additional percentage of the remaining variance of the predictand.

The F level for both entering and removing variables was specified at 3.92. For a description of the significance of this value of the F level, see section 7. The program then computed the predicted values and the deviations from the actual values, as well as the RMS error.

When we are dealing with multivariate analysis, estimation of component variances is sometimes useful. However, in the case of several variables added, this was not possible due to the non-independence of the predictors. This aspect is also dealt with in section 7.

6. The form of the forecast equations.

For forecasts of this kind to be useful, it is necessary that a

change in the variable to be predicted be attended by some corresponding change in the other variables. Based upon section 5, we can express the value of the dependent variable, Y, in terms of the several independent variables, X_i. The multiple regression equation for obtaining the predicted value of Y may be written

$$Y' = a_0 + a_1X_1 + a_2X_2 + \ldots + a_iX_i \quad (1)$$

where Y' is the predicted value of Y for each set of values for X, the a_i are constants derived from the input data and the X_i's are the predictors selected by the screening process.

In the final derived regression equations, the symbol Y' denotes in turn:

N' = Predicted 24-hour south-north displacement of the system center in nautical miles. Positive (negative) values indicate northward (southward) displacement.

E' = Predicted 24-hour west-east displacement of the system center in nautical miles. Positive (negative) values indicate eastward (westward) displacement.

P' = Predicted 24-hour change in central pressure in millibars. Positive (negative) values indicate pressure increases (decreases).

The final derived regression equations are summarized in table 7, along with some intermediate truncated forms of these equations.

In the prediction equations each predictor is identified by a symbol followed by a subscript. In each case the subscript refers to the location of a grid point as specified in figure 2. The units appropriate to each predictor are described in Appendix B.

The percentage of total variance of the predictand explained by the

selection of each predictor is summarized in table 3. The predictors are listed in the order of their selection, which in turn is a result of the computer output. Generally, the first two or three predictors explain a substantial part of the variance of the dependent variable. Each additional predictor then accounts for a lesser amount.

7. Statistical analysis and results.

The BIMD 09 of the BIMD series of statistical programs was employed by the CDC 1604 electronic computer to perform this regression analysis. The BIMD 09 program of the U. S. Naval Postgraduate School Computer Center is a modification of the BIMD 09 program of the University of California at Los Angeles. The latter program is in turn a modification of an original program developed by M. A. Efroymson [1960] of the Esso Research and Engineering Company. A brief description of the program has been given in section 5 of this report.

Miller [1958] has developed a screening procedure in which the determination of the F level for significance of the contribution of a new independent variable depends upon the number of possible predictors and the number of selected predictors. This particular program is in machine language for the IBM 704 computer and is presently not available for the CDC 1604. Statistical analysis of meteorological parameters utilizing Miller's procedure has shown promising results in connection with movement and deepening of cyclones.

An important phase of the BIMD 09 program occurs in the selection of critical F levels to enter and remove variables. Once selected, these levels remain constant and do not change each time that a variable is selected (as it does in Miller's procedure). Therefore, although the criterion for selection is initially less stringent than Miller's, the

Table 3. Summary of statistical parameters of dependent data.

a. Predictand: South-north displacement

Predictor	F level upon entry	S_y after entry	Cumulative P.R.	P.R.	"t" level of coefficient final equation	"t" percentile
z_{74}	24.7215	228.5312	13.75	13.75	4.5349	$>$ .99
$\underline{z}_{34}$	31.6323	208.0158	28.53	14.78	4.1901	$>$ .99
$\underline{T}_{56}$	18.0628	196.9019	35.96	7.43	7.0627	$>$ .99
T_{43}	8.3023	192.1551	39.01	3.05	4.5353	$>$ .99
p_{22}	16.9421	182.3900	45.05	6.04	4.6407	$>$ .99
p_{97}	11.0965	176.3137	48.65	3.60	3.8615	$>$ .99
p_{85}	4.3843	174.2636	49.84	1.19	2.0939	$\doteq$ .96

$$s_y = 246.0512 \text{ nm}$$
$$R = .7060$$
$$F_{(7,142)} = 20.1538$$
$$F_{(.99)} = 2.77$$

Mean actual movement:	-74 nm
Range of actual movement:	-875 to 585 nm
Range of predicted movement:	-662 to 305 nm
Range of errors:	-379 to 519 nm

Table 3 (continued).

b. Predictand: West-east displacement

Predictor	F level upon entry	S_y after entry	Cumulative P.R.	P.R.	"t" level of coefficient final equation	"t" percentile
z_{52}	31.1193				7.3955	> .99
z_{65}	13.1229	210.0299	31.08		9.1156	> .99
Δz_{25}	8.7252	204.6491	34.57	3.49	4.0145	> .99
λ	10.7947	198.0252	38.74	4.17	5.3130	> .99
ΔP_{63}	11.8884	190.8190	43.07	4.33	3.2606	> .99
P_{84}	8.5280	186.0237	45.94	2.87	4.4415	> .99
P_{85}	5.9933	182.8148	47.79	1.85	2.7397	> .99
P_{33}	5.4654	179.9673	49.40	1.61	3.0916	> .99
P_{74}	4.1099	177.9872	50.51	1.11	2.0273	≐ .96

s_y = 253.0019 nm
R = .7107
$F_{(9,140)}$ = 15.8744
$F_{(.99)}$ = 2.54

Mean actual movement: 407 nm
Range of actual movement: -520 to 1100 nm
Range of predicted movement: -87 to 866 nm
Range of errors: -653 to 509 nm

Table 3 (continued).

c. Predictand: Change in central pressure

Predictor	F level upon entry	S_y after entry	Cumulative P.R.	P.R.	"t" level of coefficient final equation	"t" percentile
P_{65}	23.5363	3.9805	13.14	13.14	4.6678	$>$ .99
Δz_{45}	15.9340	3.7937	21.10	7.96	2.9746	$>$ .99
z_{52}	12.9043	3.6488	27.01	5.91	3.7542	$>$ .99
P_{25}	10.2031	3.5390	31.34	4.33	3.5130	$>$ .99
ΔP_{72}	10.3812	3.4298	35.51	4.17	4.2298	$>$ .99
ΔP_{43}	11.9076	3.3068	40.05	4.54	3.3978	$>$ .99
Δz_{92}	5.7238	3.2535	41.97	1.92	2.9470	$>$ .99
z_{74}	5.0348	3.2082	43.57	1.60	2.3480	$\doteq$ .98
ΔP_{76}	5.1083	3.1625	45.17	1.60	2.2601	$\doteq$ .97

$$s_y = 4.2709 \text{ mb}$$
$$R = .6721$$
$$F_{(9,140)} = 12.8131$$
$$F_{(.99)} = 2.54$$

Mean actual change:	0.1 mb
Range of actual change:	-10 to 14 mb
Range of predicted change:	-7.6 to 8.1 mb
Range of errors:	-7.3 to 9.9 mb

statistical significance of each variable selected is, in general, clearly evident. The F level input necessary for a critical F limit is a function of the number of variables to be selected, which is an unknown until the regression analysis is completed.

Initially the F levels for entering and removing variables was specified at 4.5 and 0.22 respectively. The resulting three regression equations contained six, nine and nine variables respectively for the south-north, west-east and pressure-change equations.

With the above information then available, a table of F values was entered for a critical F corresponding to a confidence level of 0.95 and with one and 140 degrees of freedom. This resulted in a critical F level of 3.92 which was then used in the program for both entering and removing variables.

With the final computer print-out of the regression equations and the statistical data completed, the data were re-examined and the new cumulative percent reductions of variances were determined, and found to be consistent with the initial reductions. These statistics and others, as described below, are listed in table 3.

The overall F levels for the final equations were desired. These values would indicate the significance of the predictive power of the final equations.

Fisher [1948] describes the F test for significance of the multiple correlation coefficient as the ratio of the mean squares explained to the mean squares residual (as also used by Miller [1958]). Anderson [1960] and Panofsky and Brier [1958] give a similar test for the sample multiple correlation coefficient with independent variables from a multivariate normal distribution, as an F test consisting of a ratio of two χ^2-

distributed variables with k and n-k-1 degrees of freedom. Here n is the sample size and k is the number of variables in the regression equation. The form of the F test used to compute significance of kth regression equation was a modification of a formula of Anderson's [1960, p. 89], and is given in equation (2) below:

$$F_{(k,\ n-k-1)} = \frac{R^2}{1-R^2} \cdot \frac{n-k-1}{k} . \tag{2}$$

Here R is the multiple linear correlation coefficient. With a multiple linear correlation R, the reduced standard error, S_y, relative to the total standard error, s_y, is

$$S_y = s_y \sqrt{1-R^2}, \tag{3}$$

or, solving for R^2,

$$R^2 = 1 - \left[\frac{S_y}{s_y}\right]^2 = \text{percent reduction of variance.} \tag{4}$$

Therefore, we have

$$F_{(k,n-k-1)} = \left[\left(\frac{s_y}{S_y}\right)^2 - 1\right]\left[\frac{n-k-1}{k}\right], \tag{5}$$

which was the form of the equation used to compute the significance test for the final regression equations. For each variable added by the screening procedure, the computer print-out included the new value of S_y.

The cumulative percent reduction of variance was then computed for each step of the regression using equation (4). Thus, by subtraction of the previous cumulative percent reduction of variance, one obtains the percent reduction of variance attributable to the variable just entered. Note that in table 3 no P.R. is attributed to the first two variables individually, but only in combination. This was due to the fact that the variable z_{67} was entered at the first step of the regression, but was

removed after the third step was completed. The F level, for that variable individually, had dropped below the 0.95 significance level. This made it extremely difficult to compute the percent reduction of variance for the first variable in the final regression equation. A different program would have been necessary to compute this percent reduction of variance, but this was not done here.

The multiple linear correlation coefficient was also computed for the final equations. It is merely the square root of the final cumulative percent reduction of variance.

A test was undertaken to determine whether the coefficients in the final regression equations, taken individually, were significantly different from zero. This could be accomplished easily since the computer print-out included the standard error of the regression coefficients. Dividing the coefficient by its standard error yields the "t" statistic which was used to determine the "t" significance level listed in table 3. Note that all coefficients but the last have significance levels greater than 0.99. It should be noted that the values to the left of the double vertical line in table 3 were values computed at each stage of the regression while the "t" values to the right of this line apply only to the final regression equation.

These predictive equations were then tested on an independent sample of 50 anticyclones. The predicted values, actual values and errors are listed in table 6. Various simple statistical parameters were calculated by the computer as the 50 forecasts were generated. From these simple statistical parameters, equation (4) was used to compute the coefficient of determination (P.R. of variance) and the multiple linear correlation coefficient. These values are listed in table 4.

	S-N Displacement	W-E Displacement	Change in central pressure
S_y	221.12 nm	195.38 nm	4.19 mb
s_y	271.64 nm	217.70 nm	5.34 mb
R	.5809	.4411	.6193
R^2	.3374	.1946	.3835
P.R. variance	33.74%	19.46%	38.35%
Mean of actual	-111 nm	383 nm	0.5 mb
Range of actual	-1000 to 400	-55 to 750	-10 to 15
Range of predicted	-462 to 349	-112 to 760	-7.5 to 9.0
Range of error	-851 to 442	-375 to 451	-6.4 to 9.1
Mean of errors	0.5 nm	14.5 nm	0.4 mb
Mean absolute error	164.5 nm	158.4 nm	3.5 mb

Table 4. Summary of statistical parameters of independent data.

A "t" test was made to determine whether both samples were from the same infinite population using a significance level of 0.95. This test is described in Spiegel [1961]. As stated by Hoel [1956], the validity of this test is dependent upon whether the two samples have the same standard errors. Both propositions verified at the significance level of 0.95.

The errors in movement were plotted graphically in order to obtain a mean vector error magnitude and thus a visual representation of the deviations from the actual movement. The magnitude of the mean vector error was 254 nautical miles. This error distribution is shown in figure 6.

Note that for the dependent sample the percent reduction of variance

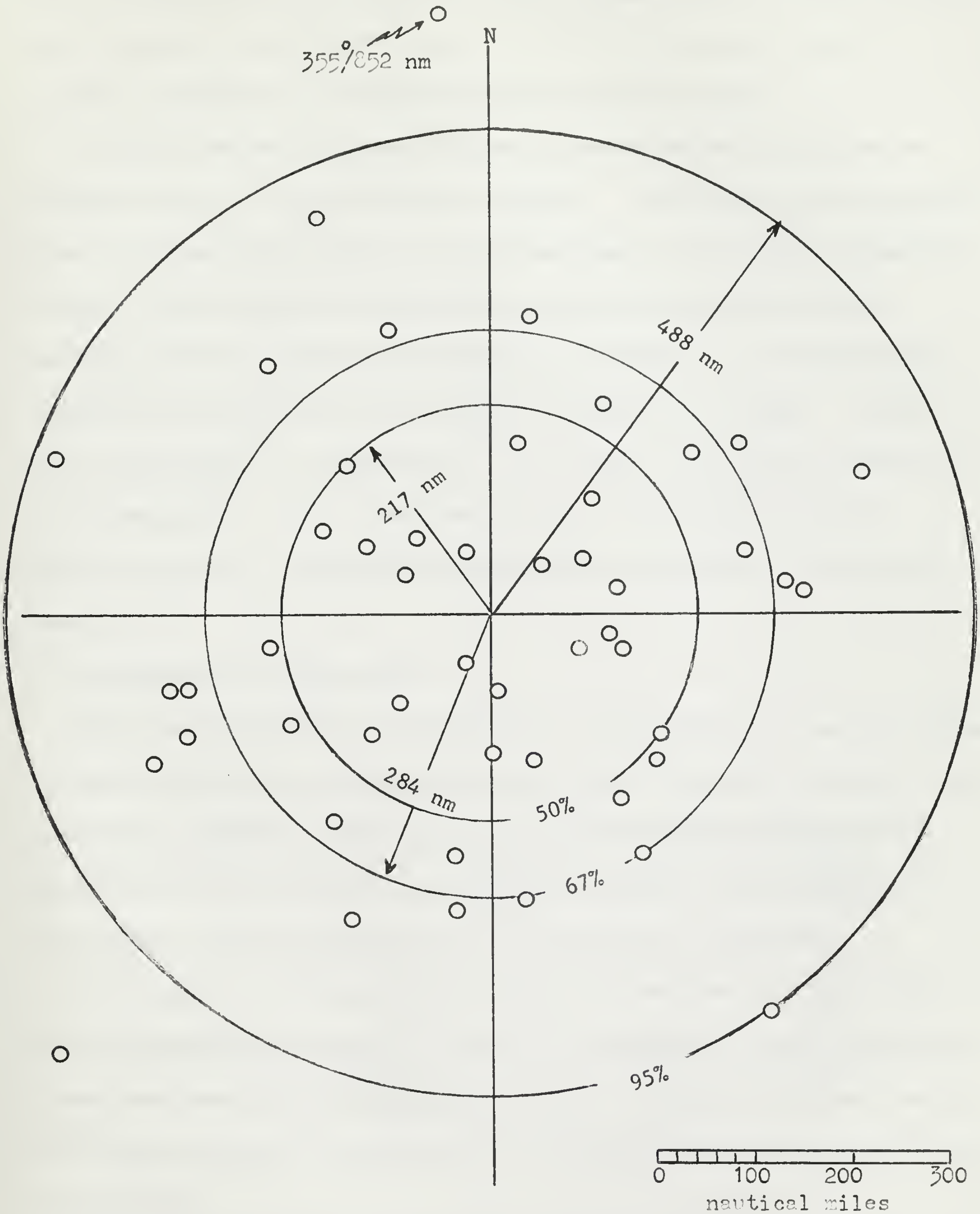

Figure 6. Error distribution of 50 independent predictions of 24-hour anticyclone displacement. Origin represents actual locations. The predicted locations are then represented by small circles plotted relative to the actual locations. The 50, 67 and 95 percentiles are shown.

for all three equations is generally 50%. This reduction compares favorably with Ostby and Veigas' results [1960] for the more predictable cyclonic systems in a considerably smaller forecast area.

The independent test shows a small loss of percent reduction of variance except for the west-east equation. This equation explained 30% less of the percent reduction of variance when tested on the independent sample. This could be accounted for by the possibility that the variables are not normally distributed. In addition, the relationship between the predictand and the predictors may not be linear. A better fit could perhaps be expected from a non-linear combination of these or other parameters. Such transformations can be programmed into the BIMD 09 program, although this was not within the scope of the present work.

8. A discussion of the errors.

Two types of errors are considered in this section: those pertaining to data acquisition; and prediction errors resulting from the use of the regression equations. Of course, the first-mentioned type causes a decrease of resolution in the prediction equations. The prediction errors have already been discussed to some extent in section 7.

With regard to data acquisition, all data recorded for this study were systematically checked for errors and corrected at each step where transformations or transcriptions occurred. In addition, a final overall check was conducted to insure that all accessible errors had been removed or corrected.

Centers were located accurately by drawing isobars to smaller intervals, even as small as 0.5-mb intervals where necessary. Nevertheless, the charts were small in their physical size, and errors of

location may be as large as $\pm$ 60 nm.

Some error exists in the measurement of distances in this problem since all distances, including the distances between grid points, were measured using a scale assumed true at latitude 45N. This is the central parallel for the forecast area.

Since the charts used were stereographic projections true at 60N, the map factor, m, is

$$m = \frac{1.86603}{1 + \sin L}. \tag{6}$$

If one assumes a movement M over a 5-degree latitude segment from 30 to 60N, use of the mean-value theorem leads to the percent error

$$\frac{\Delta M}{M} = 1 - \frac{m_L}{m_{45}} \tag{7}$$

as a function of map factor. Errors of this type are given in table 5. In general, the scale factor contributed only a small percentage error to any particular computation of movement.

Latitude	Map factor	% Error
30-35	1.213	-11.0
35-40	1.160	- 6.1
40-45	1.114	- 1.9
45-50	1.074	1.7
50-55	1.040	4.8
55-60	1.011	7.5

Table 5. Errors incurred in measuring distance, based on 5-degree latitude movements.

Although the "t" test mentioned near the end of section 7 indicates that the means could be from two samples drawn from the same population, this does not preclude the possibility that the independent sample might conceivably be from a different population. Possibly the most plausible

explanation is given by Panofsky and Brier [1958]:

> The equation with the most predictors will not necessarily yield the best fit to the second sample. The reason is that the longest equation may have actually overfitted the first sample and ascribed some of the variation due to small-scale fluctuations to one of the predictors "by accident."

In light of the above, each equation of the intermediate steps of regression is shown in table 7. In this manner, future research in the field may show better results with fewer variables as suggested by Panofsky. One can calculate the significance of the truncated regression equations by using the appropriate P.R. variance as listed in table 3 with the appropriate degrees of freedom.

Certainly some inaccuracy results from the fact that no stratification of the variables was considered. Thus, for example, it was noted in this study that cold and warm anticyclones have differing movement characteristics. It would appear that at least a bimodal distribution with respect to mean-temperature distribution would have been possible.

9. Conclusions.

The prediction equations are at least an improvement over known existing techniques. They seem to have wide applicability over a vast geographic area. The past history of an anticyclone track is not required, nor are the equations limited to a particular flow pattern or thermal distribution aloft.

It is felt, however, that a stratification of the data based on the thermal character would have resulted in a greater predictive value in the final equations. For example, had the dependent sample been restricted to cold surface highs, greater predictability would, no doubt, have resulted. It is felt that decreasing the southerly extent of the forecast area to 40N, thereby partially avoiding the subtropical high

pressure belt, would also have increased the predictive value of the forecast equations.

The results suggest that further investigation along these lines should prove quite rewarding.

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APPENDIX A

TABULATION OF INDEPENDENT PREDICTIONS

Table 6 contains predicted values of N, E and P for each of the 50 cases in the independent data sample. In addition, verifying values are listed as well as the forecast errors (N' - N), etc., which are derived directly from the computer output. Similar remarks apply to E' and E, and the component error is (E' - E). The vector error in the forecast is equal to the vector sum of the northward and eastward component errors. A diagram (fig. 6) depicts each one of these vector errors.

Negative values of P or P' represent observed or forecast anti-cyclone weakening. The error is equal to (P' - P).

All displacements are measured relative to the center of the basic square grid rather than the projection of the charts from which the data are obtained.

Table 6. Independent sample predictions of the 24-hour movements and pressure change.

Date	Lat	Long	P_{54}	E	E'	Error	N	N'	Error	Vector Error	P	P'	Error
7Jan55	38.5	90.5	1027	475	583	108	-145	80	225	027/245	- 6	0	6
19Jan55	52.0	91.3	1036	265	289	24	235	- 57	178	008/179	- 1	- 3	- 2
2Feb55	54.0	89.9	1042	120	254	134	-150	-184	- 34	104/136	6	- 1	- 7
3Feb55	51.4	87.0	1048	175	145	- 30	-230	-278	- 48	210/ 56	2	- 2	- 4
7Feb55	53.2	85.7	1025	350	311	- 39	90	-151	-241	189/244	1	0	- 1
12Feb55	44.6	98.0	1042	750	436	-314	-335	-453	-118	249/334	0	- 7	- 7
24Feb55	46.8	97.0	1043	585	549	- 36	325	27	-298	187/300	- 2	- 2	0
25Feb55	51.0	80.3	1041	575	427	-148	250	179	- 71	257/319	0	- 2	- 2
13Mar55	56.9	81.6	1030	260	258	- 2	110	- 30	-140	180/140	8	3	- 5
28Nov55	59.1	109.0	1049	150	448	298	-380	-342	38	083/301	- 5	1	6
29Nov55	52.3	104.9	1044	600	416	-184	-770	-362	408	336/445	- 6	- 5	1
2Dec55	58.1	103.8	1035	375	418	43	-200	-348	-148	164/155	4	1	- 3
3Dec55	53.0	90.0	1039	730	401	-329	10	- 62	- 72	258/335	- 4	2	6
7Dec55	57.4	94.1	1025	-45	214	259	-170	- 99	71	075/267	15	6	- 9
8Dec55	54.3	95.0	1040	50	221	171	-105	-253	-148	131/223	0	1	1
15Dec55	40.1	102.1	1040	460	358	-102	-515	-219	296	340/311	-10	- 5	4
18Dec55	48.7	107.0	1036	475	684	209	- 60	105	165	051/263	10	6	- 4
26Dec55	48.7	89.5	1037	280	455	175	- 20	-141	-121	125/209	1	- 1	- 2
27Dec55	47.9	82.5	1038	370	227	-143	0	-306	-306	205/336	3	- 1	- 4
6Jan59	38.3	82.0	1036	100	354	254	-325	-149	176	055/307	- 9	- 3	6
9Jan59	56.2	94.1	1047	90	374	284	25	-374	-399	145/490	- 7	- 3	4
11Jan59	40.3	85.7	1033	190	163	- 27	-530	-462	68	337/ 71	0	- 1	- 1
28Jan59	40.4	76.2	1026	380	423	43	- 40	267	307	007/309	4	2	- 2
30Jan59	53.9	108.6	1042	365	194	-171	-365	-276	89	297/192	3	- 1	- 4
31Jan59	47.0	99.8	1045	105	239	134	0	-187	-187	145/229	5	- 1	- 6
8Feb59	47.3	89.1	1034	700	578	-122	55	- 62	-117	226/171	2	- 2	- 4
10Feb59	56.0	100.8	1030	490	419	- 71	-1000	-149	851	355/852	5	3	- 2
11Feb59	37.9	91.0	1035	750	760	10	400	323	- 76	173/ 77	6	4	- 2
14Feb59	55.5	99.5	1035	650	742	92	-165	-183	- 18	101/ 93	- 2	1	3
15Feb59	51.0	80.5	1033	650	205	-445	-305	-143	162	290/473	- 6	0	6
18Feb59	52.6	106.0	1034	330	105	-225	-465	-209	256	318/340	1	1	0

Table 6 (continued).

Date	Lat	Long	P_{54}	E	E'	Error	N	N'	Error	Vector Error	P	P'	Error
19Feb59	44.9	98.0	1035	235	313	78	-280	-143	137	030/157	0	0	0
26Feb59	50.7	81.9	1021	320	414	94	-100	- 43	57	058/110	4	1	- 3
27Feb59	49.1	73.0	1025	410	257	-153	- 70	86	156	316/217	4	1	- 3
3Oct55	44.3	80.5	1033	575	484	- 91	0	42	42	295/ 98	- 4	- 1	3
9Oct55	40.1	81.3	1029	-55	320	375	-125	19	144	069/400	- 1	- 1	0
22Oct55	44.6	79.8	1030	380	436	56	-220	-163	57	044/ 77	2	0	- 2
12Jan52	58.1	100.2	1035	535	328	-207	- 90	-202	-112	242/233	- 8	- 2	6
29Jan52	42.7	94.6	1032	435	208	-227	-260	-292	- 32	262/226	0	- 3	- 3
12Feb52	56.4	85.0	1025	135	38	- 97	130	42	- 88	228/130	13	9	- 4
3Mar52	57.0	75.4	1036	50	-112	-162	380	169	-211	218/264	2	6	4
5Mar52	50.0	92.0	1037	220	252	32	200	- 86	-286	173/287	10	2	- 8
12Mar52	57.8	101.8	1032	275	591	316	-200	-169	31	085/317	- 3	2	5
21Mar52	59.3	102.2	1043	425	79	-346	-140	-287	-147	247/372	- 3	- 5	- 2
22Mar52	56.0	89.0	1040	575	124	-451	250	-192	-442	225/625	- 4	- 4	0
6Nov51	43.8	74.6	1043	650	522	-128	275	349	74	299/145	0	4	4
27Nov51	45.8	83.1	1032	475	600	125	-170	-187	- 17	098/125	- 3	0	3
15Dec51	39.4	97.6	1043	440	592	152	40	-203	-243	148/284	- 4	2	6
16Dec51	39.0	88.3	1039	540	668	128	- 35	- 7	28	078/130	0	- 1	- 1
24Dec51	41.1	90.8	1035	710	633	- 77	100	180	80	316/110	1	3	2

SUMMARY OF FORECAST PROCEDURE

The percentage of the total variance of a predictand explained by each selected predictor is given in table 3. In general, the first two or three predictors explain a considerable amount of the variability; subsequent predictors explain lesser amounts.

In light of the above, where time is the primary consideration, the user may be willing to sacrifice some of the predictive value of the derived equations in order to reduce the number of calculations required. The coefficients for the truncated equations obtained from the intermediate steps of regression are summarized below in table 7.

Table 7. Summary of the truncated as well as of the final form of the regression equations for northward and eastward movement and pressure change of sea-level anticyclones.

	N'		E'		P'	
k = 3	Const	1225.88867	Const	-80.84535	Const	247.51972
	z_{34}	-3.40210	z_{52}	-2.35890	P_{65}	-.23060
	$\underline{z}_{74}$	2.06476	z_{65}	2.72546	z_{52}	-.01609
	T_{56}	13.80024	Δz_{25}	-1.98448	Δz_{45}	.06027
k = 4	Const	-7.07663	Const	-844.11490	Const	356.69707
	z_{34}	-2.34752	λ	6.72400	P_{25}	-.12058
	$\underline{z}_{74}$	2.30506	z_{52}	-2.53248	P_{65}	-.21709
	$\underline{T}_{43}$	-9.59201	z_{65}	3.07734	z_{52}	-.01637
	T_{56}	15.14506	Δz_{25}	-2.83424	Δz_{45}	.05371
k = 5	Const	6030.72598	Const	-1058.52912	Const	376.14332
	P_{22}	-6.30295	λ	8.12394	P_{25}	-.11976
	z_{34}	-2.13926	P_{63}	6.97667	P_{65}	-.23663
	$\underline{z}_{74}$	2.45926	z_{52}	-2.32633	ΔP_{72}	.08134
	$\underline{T}_{43}$	-13.74407	z_{65}	2.91559	z_{52}	-.01671
	T_{56}	17.32802	Δz_{25}	-2.75370	Δz_{45}	.04914

Table 7 (continued).

	N'		E'		P'	
k = 6	Const	14646.77566	Const	5242.92812	Const	358.52542
	P_{22}	-6.42540	λ	8.89200	P_{25}	-.12976
	P_{97}	-8.14462	P_{84}	-6.50886	P_{65}	-.21104
	z_{34}	-2.09395	ΔP_{63}	7.64845	ΔP_{43}	.14006
	z_{74}	2.14122	z_{52}	-2.22808	ΔP_{72}	.08713
	$\bar{T}_{43}$	-15.83553	z_{65}	3.10035	z_{52}	-.01443
	$\bar{T}_{56}$	22.12236	Δz_{25}	-2.35194	Δz_{45}	.04065
k = 7	Const	11578.46055	Const	1537.06168	Const	333.43721
	P_{22}	-6.85958	λ	8.83391	P_{25}	-.12157
	P_{85}	5.55932	P_{84}	-12.23171	P_{65}	-.19594
	P_{97}	-9.84316	P_{85}	9.41494	ΔP_{43}	.14064
	z_{34}	-2.27834	ΔP_{63}	7.2116	ΔP_{72}	.09826
	z_{74}	1.84021	z_{52}	-2.07604	z_{52}	-.01254
	$\bar{T}_{43}$	-14.81254	z_{65}	2.89902	Δz_{45}	.04010
	$\bar{T}_{56}$	23.40104	Δz_{25}	-2.44941	Δz_{92}	.01895
k = 8			Const	5060.13022	Const	320.55524
			λ	9.65318	P_{25}	-.12599
			P_{33}	-4.96103	P_{65}	-.18277
			P_{84}	-12.37582	ΔP_{43}	.12548
			P_{85}	10.98861	ΔP_{72}	.10397
			ΔP_{63}	7.03236	z_{52}	-.02079
			z_{52}	-2.10596	z_{74}	.01295
			z_{65}	2.93012	Δz_{45}	.03841
			Δz_{25}	-2.46111	Δz_{92}	.02271
k = 9			Const	4655.21111	Const	343.12419
			λ	10.44113	P_{25}	-.12004
			P_{33}	-7.80116	P_{65}	-.21145
			P_{74}	7.60599	ΔP_{43}	.13452
			P_{84}	-16.25978	ΔP_{72}	.10122
			P_{85}	10.44469	ΔP_{76}	.07752
			ΔP_{63}	6.32668	z_{52}	-.02031
			z_{52}	-2.26007	z_{74}	.01336
			z_{65}	3.03432	Δz_{45}	.04002
			Δz_{25}	-2.60004	Δz_{92}	.02344

It should be remembered that when using the forecast procedure, northerly and easterly displacements are measured relative to the central point of the square grid shown in figure 2. Thus, on a polar

stereographic projection, easterly displacements are not measured along latitude circles, but normal to a meridian passing through the anticyclone center.

The accompanying worksheets were prepared to facilitate the employment of the derived prediction equations. In addition, they are used to demonstrate the actual procedure followed in making an operational forecast with the forecast scheme. The case in question is one included in the independent sample. At 1200Z 11Jan59 this sea-level anticyclone was located at 40.3N and 85.7W.

The symbols used in the regression equations are defined below. Specific values of predictors refer to the example forecast. Observation time is 1200Z 11Jan59. All subscripts refer to grid-point locations as specified in figure 2.

P_{22}	Surface pressure in whole millibars.
ΔP_{43}	The past 24-hour surface pressure change in whole millibars.
z_{34}	500-mb height in tens of feet with the ten-thousands digit omitted (e.g., 18,770 is recorded as 877).
Δz_{45}	The past 24-hour 500-mb height change in tens of feet (e.g., 18,670 to 18,800 is recorded as +13).
$\bar{T}_{43}$	Mean temperature in whole degrees centigrade in layer from surface to 500 mb.
λ	The longitude of the surface anticyclone center recorded to the nearest tenth of a degree.

From these worksheets the 24-hour predicted displacement is calculated to be 163 nautical miles east and 462 nautical miles south. This displacement is then measured along the square grid from the surface anticyclone center at 1200Z 11Jan59. The actual movement was 190 nautical miles east and 530 nautical miles south. The forecast change in central

pressure was -1 millibar. Actually no change occurred; the central pressure remained at 1033 mb.

The verifying sea-level pressure chart for this example is for 1200Z 12Jan59.

NORTH AMERICAN ANTICYCLONE PREDICTION WORKSHEET

SOUTH-NORTH DISPLACEMENT

P_{22}	1018	x	(-)6.85958	=	-6983.05244
P_{85}	1015	x	5.55932	=	5642.70980
P_{97}	1021	x	(-)9.84316	=	-10049.86636
z_{34}	877	x	(-)2.27834	=	-1998.10418
z_{74}	739	x	1.84021	=	1359.91519
$\bar{T}_{43}$	-15	x	(-)14.81254	=	222.18810
$\bar{T}_{56}$	-10	x	23.40104	=	-234.01040
			constant	=	11578.46055

FORECAST S-N DISPLACEMENT : -461.75974 NM

Direction (+ North, - South) : South

NORTH AMERICAN ANTICYCLONE PREDICTION WORKSHEET

WEST-EAST DISPLACEMENT

λ	85.7	x	10.44113	=	894.80484
p_{33}	1021	x	(-)7.80116	=	-7964.98436
p_{74}	1015	x	7.60599	=	7720.07985
p_{84}	1010	x	(-)16.25978	=	-16422.37780
p_{85}	1015	x	10.44469	=	10601.36035
Δp_{63}	6	x	6.32668	=	37.96008
z_{52}	814	x	(-)2.26007	=	-1839.69698
z_{65}	814	x	3.03432	=	2469.93648
Δz_{25}	-4	x	(-)2.60004	=	10.40016
			constant	=	4655.21111

FORECAST W-E DISPLACEMENT : +162.69373 NM

Direction (+ East, - West) : East

NORTH AMERICAN ANTICYCLONE PREDICTION WORKSHEET

CHANGE IN CENTRAL PRESSURE

p_{25}	1018	x	(-).12004	=	-122.20072
p_{65}	1028	x	(-).21145	=	-217.37060
Δp_{43}	-5	x	.13452	=	-.67260
Δp_{72}	12	x	.10122	=	1.21464
Δp_{76}	8	x	.07752	=	.62016
z_{52}	814	x	(-).02031	=	-16.53234
z_{74}	739	x	.01336	=	9.87304
Δz_{45}	13	x	.04002	=	.52026
Δz_{92}	26	x	.02344	=	.60944
			constant	=	343.12419

FORECAST CHANGE IN PRESSURE : - .81453 mb

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TWENTY-FOURTH ANNUAL MEETING

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TUESDAY - 18 JUNE, 1968

REGISTRATION - Mark Thomas Inn 6:00 - 9:00 pm

WELCOMING RECEPTION
Mark Thomas Inn 6:00 - 10:00 pm

WEDNESDAY - 19 JUNE, 1968

SPEAKERS' BREAKFAST FOR SPEAKERS AND SESSION CHAIRMEN OF THE DAY - Mark Thomas Inn 7:15 am

REGISTRATION DESK OPENS KING HALL, U.S. NAVAL POSTGRADUATE SCHOOL 8:00 am

TWENTY-FOURTH ANNUAL MEETING COMMENCES 9:00 am

OPENING REMARKS BY GENERAL CHAIRMAN, W. J. TULL, EXEC. V.P., ION

WELCOME BY SUPERINTENDENT, U.S. NAVAL POSTGRADUATE SCHOOL, REAR ADMIRAL ROBERT W. McNITT, USN.

REMARKS BY ION PRESIDENT, DR. GENE R. MARNER

I — SPACE SESSION 9:30 am
CHAIRMAN, DR. RICHARD M. HEAD, NASA, ERC

Orbiting Velocity Meter — S. R. Sporn, American Bosch Arma Corp., Garden City, N.Y.

Irradiation & Manual Navigation — Richard F. Haines and William H. Allen, NASA, Ames, Moffett Field, Calif.

COFFEE BREAK 10:30 - 10:45 am

Sight Reduction Tables for Orbital Navigation — William Devereux, Kollsman Inst. Corp., Syosset, N.Y.

Manual Onboard Computation Procedures & Devices for Orbital Navigation & Guidance — Samuel P. Altman, General Electric Co., Philadelphia, Pa.

WEDNESDAY - 19 JUNE (continued)

LUNCHEON — Mark Thomas Inn 12:00 - 1:30 pm

Speaker: Jon Lindbergh, Manager
Pac. N.W. and Japan,
Oceans Systems, Inc.

II — MARINE SESSION 2:00 pm
CHAIRMAN, DEAN CARL E. MENNEKEN, U.S. NAVAL P.G. SCHOOL

A Bench Mark Navigation System for Surface and Subsurface Vessels — Gilbert Fain, Raytheon Co., Portsmouth, R.I.

Yacht Navigation — Ben Warriner, Fort Wayne, Ind.

Channel Navigation & Docking of Supertankers — Jack Kritz and Morton J. Howard, Kollsman Inst. Corp., Syosset, N.Y.

COFFEE BREAK 3:30 - 3:45 pm

Marine Collision Avoidance: Human Factor Considerations for the Development and Operation of an Effective Merchant Marine Radar — Thomas D. Mara, General Dynamics, Groton, Conn.

Navigation Systems & Insurance — Walter B. Potts, Marsh & McLennan, Inc., New York, N.Y.

THURSDAY - 20 JUNE, 1968

SPEAKERS' BREAKFAST FOR SPEAKERS AND SESSION CHAIRMAN OF THE DAY —
Mark Thomas Inn 7:00 am

III — GENERAL SESSION 8:30 am
CHAIRMAN, WINFIELD H. ARATA, NORTHROP NORTRONICS

The National Plan for Navigation — Alton B Moody, FAA, Washington, D.C.

Application of Satellite Navigation Techniques to Marine & Air Navigation — Joseph Chernof, ITT Aerospace, San Fernando, Calif.

Expanded Application of Navy Navigation Satellite System in Marine & Air Navigation — E. F. Gallagher, Navy Astronautics Group, Point Mugu, Calif.

COFFEE BREAK 10:00 - 10:15 am

USAF Navigation Satellite Program — Maj. F. M. Charette, SAMSO, USAF, Los Angeles, Calif.

An Optimal Inertial/Doppler-Satellite Navigation System — R. G. Brown and L. L. Hagerman, Iowa State University, Ames, Iowa

LUNCHEON — Mark Thomas Inn 12:00 - 1:30 pm

Speaker: Brig. Gen. Robert A. Duffy, USAF
Deputy for Re-entry Systems,
SAMSO

IV. — GENERAL SESSION 2:00 pm

Flight Test Performance of an Airborne Omega Equipment Set — G. Rex Morin, Lear Siegler, Inc., Grand Rapids, Mich.

Computerized Airborne Omega Navigation — D. B. Daniel, Northrop Nortronics, Hawthorne, Calif.

Omega — Inertial Hybrid Receiver — Winslow Palmer, Consultant, Babylon, N.Y.

COFFEE BREAK 3:30 - 3:45 pm

Precise Positioning of a Ship at Sea Utilizing VLF Transmissions — Method & Results — R. Bernstein, G. N. Ruppert, and C. O. Bowin, IBM/WHOI, Gaithersburg, Md.

Time-Difference Position-Determination System for Aerospace & Terrestrial Applications — J. E. Gaffney, Jr., IBM, Federal Systems Division, Gaithersburg, Md.

A N N U A L B A N Q U E T

OFFICERS' OPEN MESS
U.S. NAVAL P.G. SCHOOL

RECEPTION: 6:00 pm DINNER: 7:30 pm

PRESENTATION OF ANNUAL AWARDS BY DR. GENE R. MARNER, PRESIDENT, THE INSTITUTE OF NAVIGATION.

FRIDAY - 21 JUNE, 1968

SPEAKERS' BREAKFAST FOR SPEAKERS AND SESSION CHAIRMAN OF THE DAY
Mark Thomas Inn 7:00 am

V — AIR SESSION 8:30 am
CHAIRMAN, JOSEPH A. PARINI,
LEAR SIEGLER, INC.

Separation Assurance Over the North Atlantic — Nathaniel Braverman — FAA, Atlantic City, N.J.

Commercial Navigation for the 1970's — R. H. Waldman, International Airline Navigators Council, Quebec, Canada

Trends in Computer Technology — Glen M. Harold, Sperry Rand Corp., St. Paul, Minn.

COFFEE BREAK 10:00 - 10:15 am

Integrated Inertial Velocity-Aided & Position-Aided Aircraft Navigation — Dr. Boris Danik, General Precision, Inc., Wayne, N.J.

Area Navigation — A Major Capability Improvement for Air Traffic Control — Glen A. Gilbert, Glen A. Gilbert Associates, Miami, Fla.

LUNCHEON — Mark Thomas Inn 12:00 - 1:30 pm

Speaker: Willis M. Hawkins, V.P. Science & Eng., Lockheed Aircraft Corp.

VI — AIR SESSION 2:00 pm

The Integration of Air Navigation Systems — John Larsen, Consultant, Annapolis, Md.

A Navigation Satellite System for Use with Army Tactical Aircraft — Keith D. McDonald and Laurin G. Fischer, Communications & Systems, Inc., Falls Church, Va.

Optimum Integration of Aircraft Navigation Systems — William Zimmerman, Dynamics Research Corp., Stoneham, Mass.

COFFEE BREAK 3:30 - 3:45 pm

Electronic Terminal Guidance for All-Weather VTOL Operations — David W. Young, Lockheed Electronics Co., Plainfield, N.J.

CAINS: Inertial Navigation for Carrier Aircraft in the 1970's — R. S. Vaughn, Naval Air Development Center, Johnsville, Pa.

MEETING ENDS ABOUT 4:45 pm

TWENTY-FOURTH ANNUAL MEETING

General Chairman .... W. J. TULL

Technical Chairman .... LOREN E. DeGROOT

Arrangements Committee:

Chairman .... RALPH B. NEAL
Assistant Chairman-Registration ...
... LT. COL. PHILLIP E. HUKILL, USA
Assistant Chairman .... WILLIAM J. PYESTNER
Assistant Chairman .... THOMAS E. DAWSON
Assistant Chairman-Publicity .... HAL WALTON
Ladies' Program .... JOYCE NEAL

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The Institute of Navigation

NATIONAL OFFICE: 711 14th Street, N.W., Suite 912
Washington, D.C. 20005

PURPOSE OF THE ION

The Institute of Navigation is a scientific, non-profit organization, founded in 1945. Its programs are directed toward elevating standards of navigation by coordinating the knowledge and achievements of practicing navigators, scientists and those involved in the development and production of navigational equipment.

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THE JOURNAL

Editor .... FREDERICK FRANKLIN

Executive Director ...
... CAPTAIN ROSS E. FREEMAN, USN (Ret.)

REGISTRATION

A registration form is attached (reverse of this panel). Please register and sign up for meal functions early. If the Treasurer is so requested not later than 48 hours in advance of the meeting, payment for registration fee and meals will be refunded.

HOTEL ACCOMMODATIONS

ION Headquarters will be located at the Mark Thomas Inn, P.O. Box 1711, Monterey, California where a block of rooms is being held for The ION until 5 June. MONTEREY IS A POPULAR RESORT AND GOLFING AREA, SO MAKE YOUR RESERVATIONS EARLY. Room rates are as follows:

Single	- $ 9.00 to $18.00
Twin	- $13.00 to $22.00

When requesting a reservation, state that you will be attending The ION Annual Meeting.

FUTURE ION MEETINGS SCHEDULED

6-7 November, 1968

NATIONAL MARINE NAVIGATION MEETING
New Orleans, Louisiana

15-16 January, 1969

FIFTH UNCONVENTIONAL INERTIAL SENSORS SYMPOSIUM (Classified) — NAVAL APPLIED SCIENCE LABORATORY, BROOKLYN, N. Y. CO-SPONSORED WITH THE NAVY AND AIR FORCE.

5-6 March, 1969

NATIONAL SPACE MEETING
Houston, Texas (Tentative)